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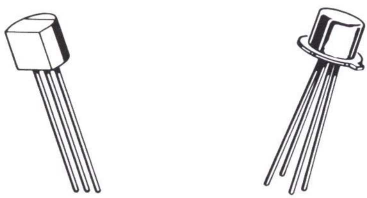
Semiconductors

TIPS ON USING FET's



- FET Cross-Reference Guide
- 9 FET Project Circuits
- Tips on Using FET's

9 PROJECTS

Build These 9 Interesting and Useful Projects Plus Many Other Published Projects With These Prime Quality Devices

- One N-Channel Audio FET
- One N-Channel RF FET
- One NPN Silicon Transistor
- One PNP Silicon Transistor

"The FET is probably the most important single discovery made to date in the entire semiconductor field."

Many construction and project articles have appeared in various books and magazines using FET's, a large number of which specify the HEP devices included in this kit. For other FET requirements the HEP FET cross-reference included in this brochure should be checked.

The invention of the transistor has had a profound affect upon our world of electronic technology as well as our daily lives. If the FET had been discovered before the transistor, rather than vice versa, these affects and changes would have come about even faster. This statement is based on the similarity of the FET and the vacuum tube.

This brochure is being presented with the assumption that the reader has attained a basic understanding of the construction and application of conventional transistors. Therefore, only the highlights and more significant details of FET construction and application will be discussed. Also, it should be noted that there is an abundance of technical literature and textbooks that are available for the serious student, technician, and engineer.

FET stands for Field Effect Transistor. As the name implies, the "transistor" control is "effected" by an electric "field".

Until the advent of the FET there was no need for differentiation between transistors, however, the FET made it necessary to add some distinguishing nomenclature. Thus, BIPOLAR refers to the familiar type transitor and UNIPOLAR refers to FET's. The term bipolar is used for transistors because they operate on the principle of two carriers, majority and minority (holes and electrons). The term unipolar is used for FET's because they operate on the principle of one carrier, which is a majority carrier.

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6518 PRINTED IN USA 12-71 IMPERIAL LITHO B-26221

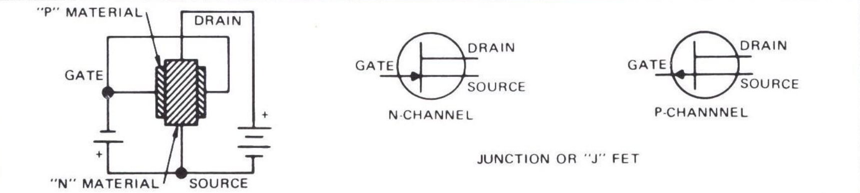
Just as bipolar transistors are available in NPN and PNP versions, FET's also come in different configurations as shown in Table I and illustrated in Figure 1.

Figure 2 and Table II present a basic comparison of a FET, bipolar transistor, and vacuum tube. (Remember that the transistor is a current amplifier and the FET and vacuum tube are voltage amplifiers.)

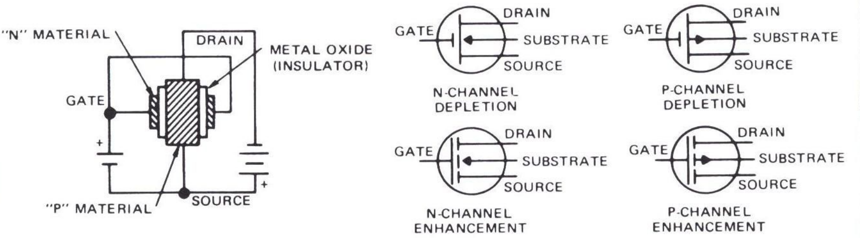
Table I. FET Configurations

JFET (junction type)
- N-Channel depletion mode
- P-Channel depletion mode

MOS FET or IG FET
- N-Channel depletion mode
- P-Channel depletion mode
- N-Channel enhancement mode
- P-Channel enhancement mode



N-Channel FET (for P-Channel, N and P materials and battery polarities are reversed)



P-Channel MOS FET (Metal Oxide Semiconductor FET) also referred to as IG FET (Insulated Gate FET) (for N-Channel, N and P materials and battery polarities are reversed)

Figure 1. Typical FET Construction (simplified) and Standard Symbols

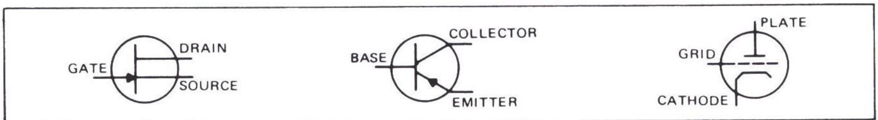


Figure 2. Symbolic Comparison of FET, Bipolar Transistor, and Vacuum Tube

Table II. Characteristics Comparison of FET's, Transistor, and Vacuum Tube

Characteristic	J FET	MOS FET	Transistor	Tube
Impedance (input) (typical in ohms)	High (10 meg)	Very high (100 meg)	Medium to low (1000Ω)	Very high (100 meg)
Average Life	Long	(Long, see text)	Long	Short
Gate/Base/Grid Current (typical; in amperes)	1×10^{-9}	1×10^{-12}	1×10^{-6}	1×10^{-9}
Noise (internal)	Low	Low (variable)	Medium to low	Low
Amplification Factor	Low	Low	Low to high	Low to high

How a J FET Works

The junction FET utilizes a PN junction, as indicated by the arrow in the symbol. the "channel" of conducting material is surrounded by a material of the opposite polarity and has the ability to constrict the flow of current through the channel. This constriction can be compared with the ability to control the flow of water through a garden hose by pinching it together.

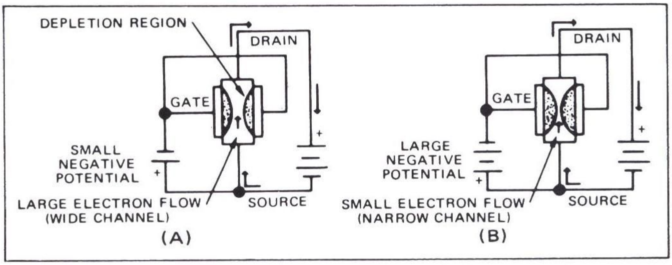


Figure 3. Biasing and Electron Flow — N-Channel FET

The "field" is the depletion region formed by the reverse biased PN junction. (The FET exhibits a high input impedance because of this reverse bias.) The depletion principle is illustrated in Figure 3 and can be roughly compared to a reverse biased PN junction in a standard transistor.

As illustrated in Figure 3 (A) a small negative potential applied between the gate and source results in a large electron flow, due to the small depletion area and resultant wide channel. An increase in gate-to-source reverse bias enlarges the depletion area and narrows the channel, as shown in 3 (B). The reverse bias can be increased to a point where no current flows through the channel. This point is referred to as the V_P or "pinch-off" voltage and will vary to some degree with applied potentials. Unlike the ordinary transistor (bipolar) virtually no current flows in the source-to-gate direction, thus resulting in a very high input impedance.

MOS is the acronym for Metal Oxide Semiconductor and IG for Insulated Gate. MOS and IG are synominous. A J is used to refer to a junction device. It should be noted that the term J FET is rarely used anymore, just FET being accepted for this type of device. However, the MOS or IG FET will always be identified by one or the other acronyms.

Until recent manufacturing break-throughs, MOS FET's suffered from short-life problems and were inherently unstable. However, these drawbacks have been overcome and the devices being produced today reflect the quality and long life that is expected from semiconductors in general.

Glossary of FET Terms and Parameters

Following are the most common and important terms used with FET's and MOS FET's.

V_{DS} (or V_{DSS}) – maximum voltage, drain to source, typically 25 to 100 volts.

V_{GS} – maximum voltage, gate to source, typically 25 to 100 volts.

V_P – pinch-off voltage, gate to source voltage required to eliminate any current flow in channel. (Increases with temperature increase. Varies with V_{DS}).

BV_{GSS} – gate to source breakdown voltage when reverse biased and $V_{DS}=0$, typically 25 to 100 volts.

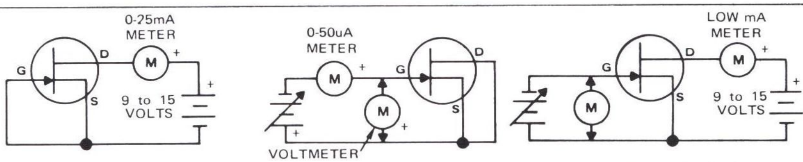
I_{DSS} – drain to source current with gate shorted to source. (Junction FET – drain to source current with $V_{GS}=0$, decreases with temperature increase). (MOS FET, enhancement mode, drain to substrate current, increases with temperature increase.) Typically 0.5 to 15 mA.

I_{GSS} – gate to source leakage current when $V_{DS}=0$. (Increases rapidly with increase in temperature for junction FET, slightly for MOS FET.) Typically 0.001 to 100 nano Amp.

Gm|yfs| – transconductance. Small signal, common source, short circuit, forward transfer conductance. Typically 1500 to 6000 μmhos.

Figure 4 illustrates some of the typical FET electrical characteristics that can be measured with simple test equipment: (diagrams show N-channel devices, for P-channel reverse meter and battery polarities).

Another simple test for the condition of a FET or MOS FET can be conducted as shown in Figure 5, using only an ohmmeter. Disconnect the FET from the circuit and measure the resistance between the terminals as shown. (Polarity of the meter must be known; polarities will be reversed for P-channel devices; indicated readings are approximate.)



(A) Test for I_{DSS} (current, drain to source with gate shorted to source). Typical 0.5 to 15 mA.

(B) Test for BV_{GSS} (breakdown voltage, gate to source with drain shorted to source). Typical 25 to 100 V. Increase voltage until Ammeter starts to deflect. Read voltmeter directly.

(C) Test for V_P (pinch-off voltage). Increase gate to source voltage until drain current is zero. Read voltage directly.

Figure 4. Simple FET Tests

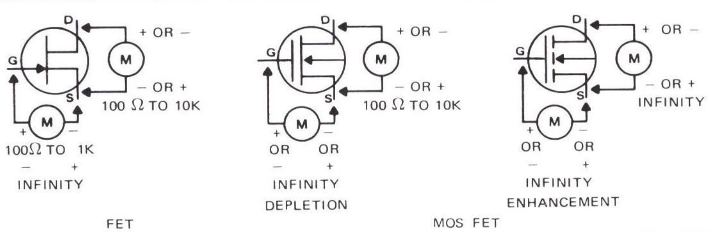


Figure 5. FET Tests Using an Ohmmeter

An important characteristic not specified as a parameter is frequency. The approximate operating frequency range, stated as audio, video, VHF, or UFH is usually stated on the manufacturer's data sheet. For example, the HEP 801 is classified as an audio through VHF device.

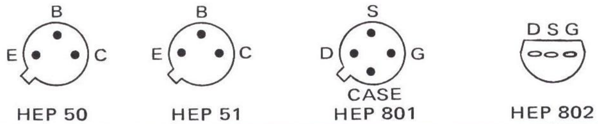
Most FET's are symmetrical in construction. In other words the gate is located halfway between the drain and source and since the material that makes up the channel is evenly doped, it is possible to interchange the drain and source leads with no noticeable change in operating behavior. The HEP 801 and 802 are examples of symmetrical FET's.

J FET's can be handled the same as transistors are handled, soldered, and tested; MOS FET's cannot. Due to the unique construction, MOS FET's are very sensitive to static electricity and merely touching a floating gate lead with a statically charged finger can ruin the device. The insulating layer separating the gate and channel is in the order of microns in thickness and the static electricity can easily puncture this layer and ruin the device. For this reason the leads of a MOS FET should always be shorted together when the device is not connected into a circuit.

In the design and construction of FET circuits the I_{DSS} is probably the most important parameter. A specific device type might have a broad I_{DSS} current range, for example, 1 mA to 10 mA and any single device will fall within this range. A well designed circuit must operate at both of these extremes. Should a circuit be encountered where a device fails to function it could be due to this I_{DSS} factor, and resistor values should be varied in an attempt to optimize the circuit operation.

A careful analysis of the following circuits will reveal some of the very useful features of FET's and also show how they can be used in conjunction with bipolar transistors to provide a high performance circuit much better than either type of device could do by itself. It should also be noted that the HEP devices included in this kit are applicable to a great number of projects that have been published in various electronic magazines and journals.

BASING DIAGRAMS (Bottom View)



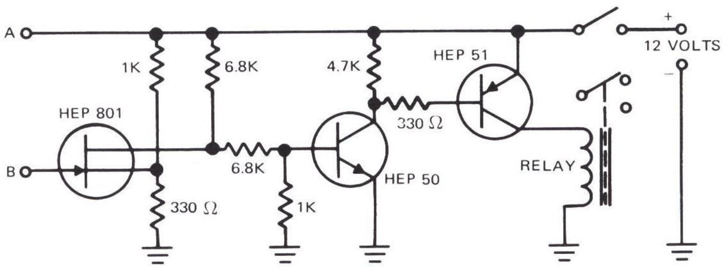
TIMER – MOISTURE DETECTOR – LIGHT ACTIVATED RELAY

USES:
Build Basic Control Unit and Add On As Desired

FEATURES:
TIMER – With 100 mfd and resistors as shown, range is approx. 5 sec. to 50 sec. change R and C to alter range.

MOISTURE DETECTOR – Printed circuit board pattern or network of wires close together to allow moisture to bridge contacts.

LIGHT ACTIVATED RELAY – Circuit activates when light strikes photo device.

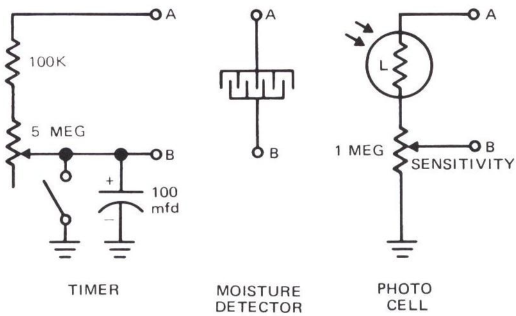


PARTS LIST:
1 HEP 801
1 HEP 50
1 HEP 51
1 Relay, 12 Volt
1 SPST Switch
2 Resistors, 1K, 1/2 Watt, ± 10%
2 Resistors, 330 Ω, 1/2 Watt, ± 10%
2 Resistors, 6.8K, 1/2 Watt, ± 10%
1 Resistor, 4.7K, 1/2 Watt, ± 10%

TIMER PARTS
1 Resistor, 100K, 1/2 Watt, ± 10%
1 Potentiometer, 5 meg.
1 Electrolytic Capacitor, 100 mfd, 15V
1 Push Button Switch, Norm. Open

MOISTURE DETECTOR PARTS
Grid Pattern, 1/16" spacing min.

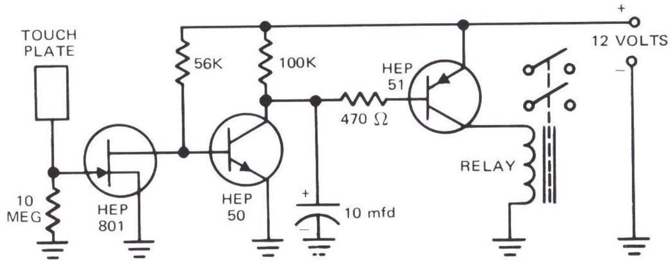
LIGHT ACTIVATED RELAY
1 Potentiometer, 1 meg.
1 Photo device



TOUCH SWITCH (Capacitance Switch)

USES:
Can Be Used to Turn On or Off a Variety of Circuits

FEATURES:
Touch the Plate and Operate the Relay



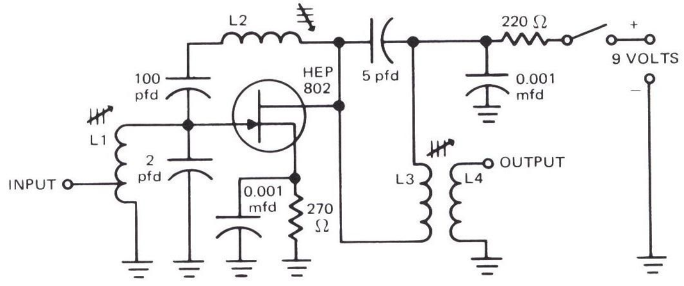
PARTS LIST:
1 HEP 801
1 HEP 50
1 HEP 51
1 Resistor, 10 meg., 1/2 Watt, ± 10%
1 Resistor, 56K, 1/2 Watt, ± 10%
1 Resistor, 100K, 1/2 Watt, ± 10%
1 Resistor, 470 Ω, 1/2 Watt, ± 10%
1 Electrolytic Capacitor, 10 mfd, 15V
1 Relay, 12 Volt
(Touch plate can be any small piece of metal — keep close to gate terminal)

The wide variety of relays makes this circuit a challenge to the ingenuity of the experimenter. Latching relays, time delay, stepping, etc. will offer many unique possibilities.

2-METER (150 MHz) PREAMPLIFIER

USES:
Provides Low-Noise Amplification Ahead of Receiver

FEATURES:
14dB Gain at Low Noise



PARTS LIST:
1 HEP 802
1 Ceramic Capacitor, 0.001 mfd, 10V
1 Mica Capacitor, 2 pfd, 10V
1 Mica Capacitor, 5 pfd, 10V
1 Mica Capacitor, 100 pfd, 10V
1 Resistor, 220 Ω, 1/2 Watt, ± 10%
1 Resistor, 270 Ω, 1/2 Watt, ± 10%
1 SPST Switch
1 9 Volt Battery

(All coils wound on brass-slug ceramic form)
L1 5 1/4 turns, tapped at 1 1/4 turn, #26
L2 9 1/2 turns, #34
L3 5 turns, #26
L4 1 1/4 turn, #26, at low end of L3

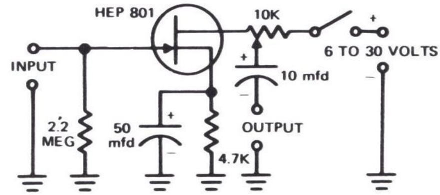
NOTE: All leads should be kept as short as possible (pc board is recommended)

MICROPHONE or PHONO PREAMPLIFIER

USES:
Preamplifier for ceramic or crystal microphone or phone cartridge

FEATURES:
Excellent Frequency Response
Operates on Wide Range of Supply Voltages

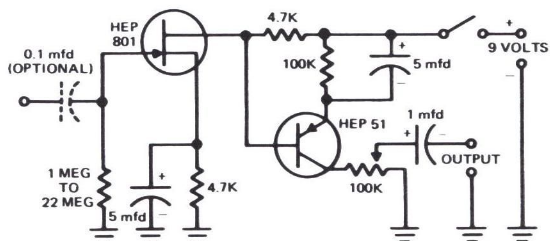
PARTS LIST:
1 HEP 801
1 Resistor, 2.2 meg, 1/2 Watt, ± 10%
1 Resistor, 4.7K, 1/2 Watt, ± 10%
1 Potentiometer, 10K, Audio Taper
1 Electrolytic Capacitor, 10 mfd, 25V
1 Electrolytic Capacitor, 50 mfd, 25V
1 SPST Switch
Battery as Desired



AUDIO AMPLIFIER

USES:
Amplify Any Low-Level Audio Signal

FEATURES:
High Impedance Input
Low Current Drain (200-400 μA)
Freq. Range 10 Hz to 30 KHz
Low Impedance Output
Typical Gain 200 to 400



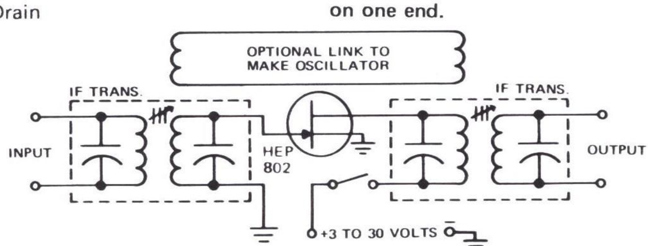
PARTS LIST:
1 HEP 801
1 HEP 51
1 Resistor, 1 meg to 22 meg, 1/2 Watt, ± 10%
1 Resistor, 100K, 1/2 Watt, ± 10%
2 Resistors, 4.7K, 1/2 Watt, ± 10%
1 Potentiometer, 100K, Audio Taper
2 Electrolytic Capacitors, 5 mfd, 15V
1 Electrolytic Capacitor, 1 mfd, 15V
1 SPST Switch
1 9 Volt Battery
1 Capacitor, 0.1 mfd, 25V (optional)

INTERMEDIATE FREQUENCY AMPLIFIER (or OSCILLATOR)

USES:
Amplify 50 KHz, 455 KHz, 10.7 MHz, or any Frequency Within the Limits of the FET

FEATURES:
High Impedance Provides Minimum Loading
Low Current Drain

NOTE: This circuit can be changed into a stable oscillator (tuned drain-tuned gate) by simply link coupling the input to the output. (Coupling inputs and outputs of IF transformers can also be used.) If circuit doesn't oscillate, reverse link on one end.



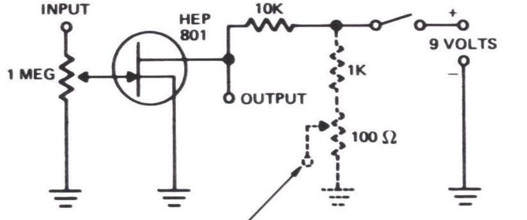
PARTS LIST:
1 HEP 802
2 IF transformers or tuned circuits as desired
1 SPST switch
1 Battery (3 to 30 Volts)

OPTIONAL PARTS:
Link – 6 turns of wire, each end. Approx. same diameter as coils.

DC AMPLIFIER

USES:
Can be used with oscilloscope, vtvm, or other circuits requiring dc amplification. Can also be used as a relay amplifier

FEATURES:
Input – 0 to -1.5 Volt
Output – 0.4 to 9 Volts
Output can go to zero if an offset circuit is supplied



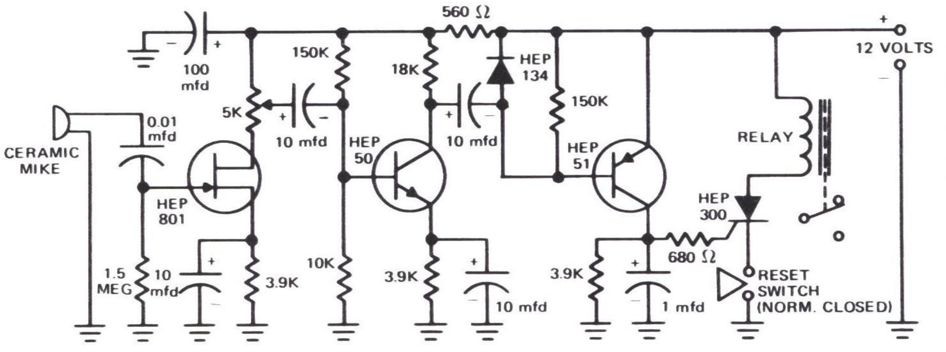
PARTS LIST:
1 HEP 801
1 Resistor, 10K, 1/2 Watt, ± 10%
1 Potentiometer, 1 meg, linear
1 SPST Switch
1 9 Volt Battery

OPTIONAL PARTS:
1 Resistor, 1K, 1/2 Watt, ± 10%
1 Potentiometer, 100 Ω, linear

SOUND ACTIVATED RELAY

USES:
Control any circuit with a clap of the hands or sharp sound.

FEATURES:
Adjustable Sensitivity
Circuit Remains Activated Until Manually Reset

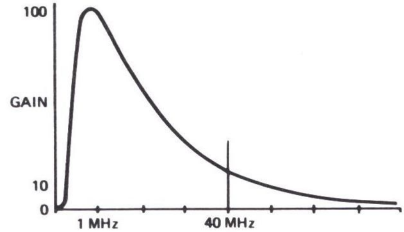


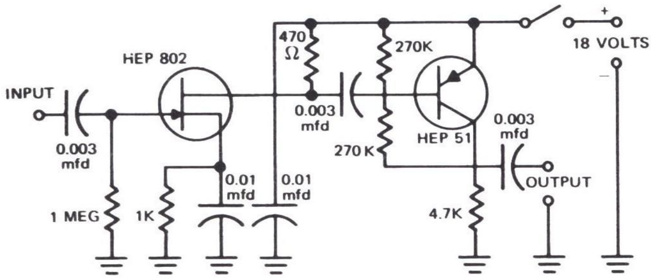
PARTS LIST:
1 HEP 801
1 HEP 50
1 HEP 51
1 HEP 134
1 HEP 300
1 Ceramic Mike
1 Relay, 12 Volt
1 Potentiometer, 5K, Linear Taper
1 Resistor, 1.5 meg, 1/2 Watt, ± 10%
3 Resistors, 3.9K, 1/2 Watt, ± 10%
1 Resistor, 18K, 1/2 Watt, ± 10%
1 Resistor, 10K, 1/2 Watt, ± 10%
1 Resistor, 680 Ω, 1/2 Watt, ± 10%
1 Resistor, 560 Ω, 1/2 Watt, ± 10%
2 Resistors, 150K, 1/2 Watt, ± 10%
1 Ceramic Capacitor, 0.01 mfd, 25V
1 Electrolytic Capacitor, 1 mfd, 15V
4 Electrolytic Capacitors, 10 mfd, 15V
1 Electrolytic Capacitor, 100 mfd, 15V
1 Push-Button Switch, Norm. Closed

BROADBAND RF AMPLIFIER

USES:
Amplifies RF Signals Over the Range of 1 MHz to 40 MHz

FEATURES:
High Input Impedance
High Signal-to-Noise Ratio





PARTS LIST:
1 HEP 802
1 HEP 51
1 Resistor, 1 meg, 1/2 Watt, ± 10%
1 Resistor, 1K, 1/2 Watt, ± 10%
1 Resistor, 4.7K, 1/2 Watt, ± 10%
1 Resistor, 470 Ω, 1/2 Watt, ± 10%
2 Resistors, 270K, 1/2 Watt, ± 10%
2 Ceramic Capacitors, 0.01 mfd, 25V
3 Ceramic Capacitors, 0.003 mfd, 25V
1 SPST Switch
2 9 Volt Batteries

FET Cross Reference for Hobbyist Experimenters*

Type to be Replaced	HEP Replacement
2N3819	802
2N3882	803
2N4221	801
2N4222	801
2N5163	802
2N5248	802
2SJ11	803
2SJ12	803
40461	801
48-134944	801
C673	801
C674	801
C684	801
C684A	801
C685	801
D1101	801
D1102	801
D1301	801
D1302	801
D1303	801
FE100	801
FE100A	801
FE102	801

Type to be Replaced	HEP Replacement
FE102A	801
FE104A	801
FE400	801
FE402	801
FE402A	801
FE404A	801
FF400	801
HA2001	801
HA2010	801
M100	801
M101	801
MFE4001	803
MFE4008	803
MFE4009	803
MFE4010	803
MFE4011	803
MPF102	802
MPF103	801
MPF104	801
MPF105	801
MPF151	803
MPF161	803

Type to be Replaced	HEP Replacement
SPF024	801
TIS14	801
TIS34	802
TIS58	802
TIS59	802
U1177	801
U1178	801
U1180	801
U1181	801
U1285	801
U1322	801
U1323	801
U1324	801
UC20	801
UC100	801
UC105	801
UC110	801
UC115	801
UC120	801
UC125	801
UC410	803

*For a complete cross reference of all HEP devices refer to the latest edition of the HEP Cross-Reference Guide.